GOES-16 On-Station Custom Maneuver Generation with *FocusSuite*

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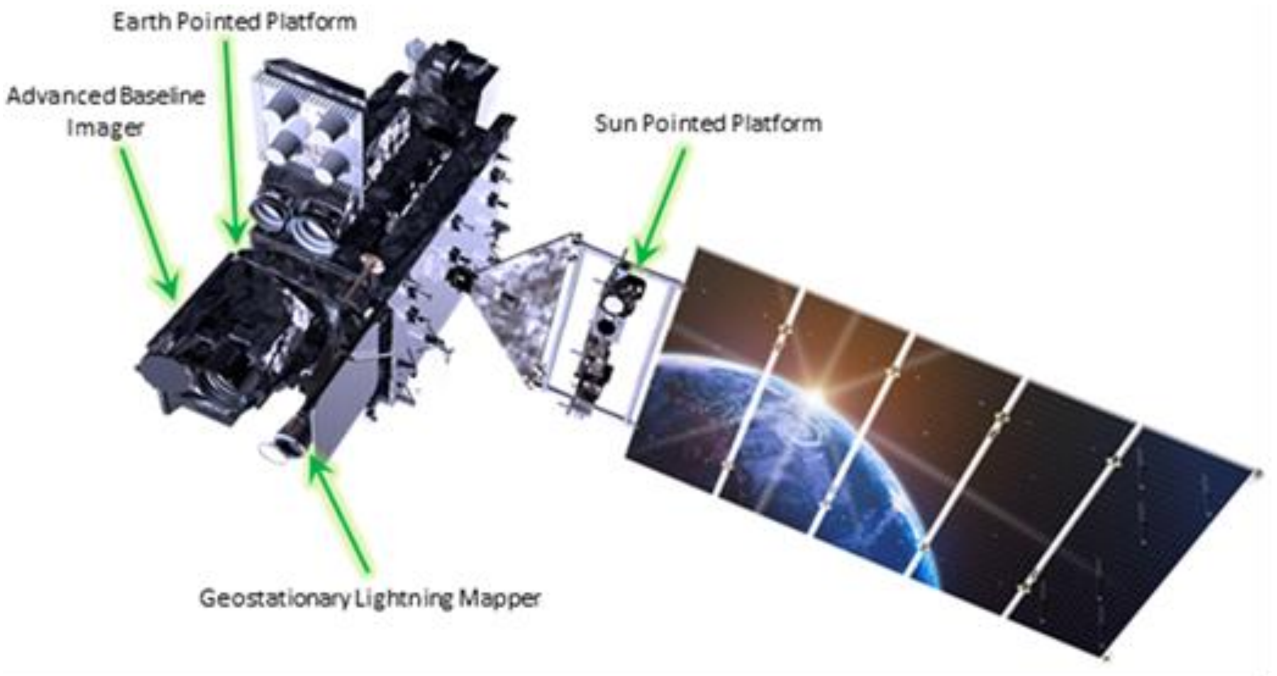
Introduction

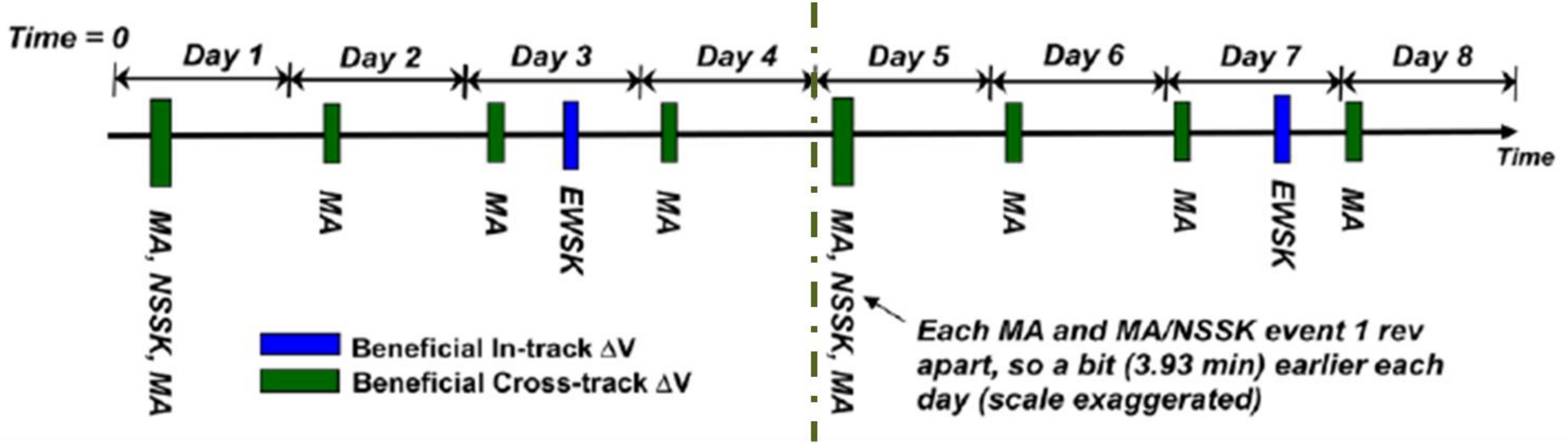
- GOES-R Series
  - Series of four geostationary weather satellites
  - Launches in 2016, 2018, 2022, and 2024
  - Have strict station-keeping requirements to keep science instruments active



GOES-R Series Spacecraft in Operational Configuration.[1]

Station-Keeping

- Three types of station-keeping maneuvers:
  - Twice-weekly EWSKs and NSSKs
  - Daily MAs



Nominal GOES-R Series Station-Keeping Cadence.[2]

Thrusters & Fuel Usage

Breakdown of AJT and LTR Thruster Count and Intended Use in GOES-R Series Spacecraft.

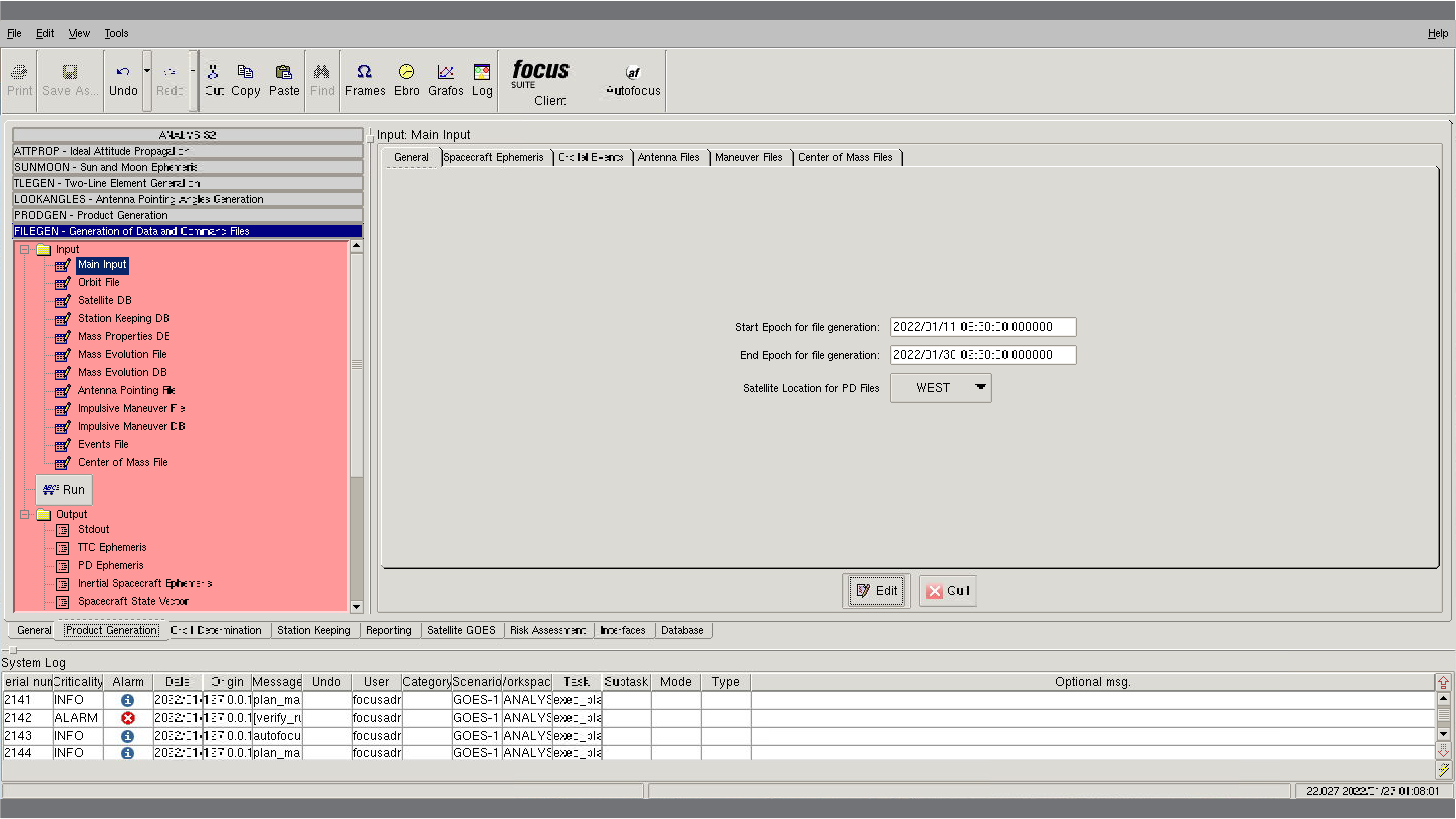
Thruster Type	Count	Intended Use
Low-Thrust Reaction engine assembly (LTR)	16	MA maneuvers and EWSK maneuvers
ArcJet Thruster (AJT)	4	NSSK maneuvers

Station-Keeping Fuel Usage for GOES-16 and GOES-17 During Their First Full Years On-Orbit.

Spacecraft	MA Fuel Usage (kg)	EWSK Fuel Usage (kg)	NSSK Fuel Usage (kg)	Total Station-Keeping Fuel Usage (kg)
GOES-16	7.49	6.20	31.55	45.24
GOES-17	5.92	5.99	33.23	45.14

Spacecraft Navigation

- Maneuver Planning
  - We use *FocusSuite* by GMV
  - We utilize the *Autofocus* automation toolbox
- MOST develops *Autofocus* scripts for NOAA planners to use for:
  - Maneuver planning
  - Maneuver reconstruction
  - Orbit determination
- The system works well in nominal operations



File Edit View Tools
Help
Print Save As... Undo Redo Cut Copy Paste Find Frames Ebro Grafos Log
focus SUITE Client
Autofocus
ANALYSIS2
ATTPROP - Ideal Attitude Propagation
SUNMOON - Sun and Moon Ephemeris
TLEGEN - Two-Line Element Generation
LOOKANGLES - Antenna Pointing Angles Generation
PRODGEN - Product Generation
FILEGEN - Generation of Data and Command Files
Input
Main Input
Orbit File
Satellite DB
Station Keeping DB
Mass Properties DB
Mass Evolution File
Mass Evolution DB
Antenna Pointing File
Impulsive Maneuver File
Impulsive Maneuver DB
Events File
Center of Mass File
Run
Output
Stdout
TTC Ephemeris
PD Ephemeris
Inertial Spacecraft Ephemeris
Spacecraft State Vector
Input: Main Input
General
Spacecraft Ephemeris
Orbital Events
Antenna Files
Maneuver Files
Center of Mass Files
Start Epoch for file generation: 2022/01/11 09:30:00.000000
End Epoch for file generation: 2022/01/30 02:30:00.000000
Satellite Location for PD Files WEST
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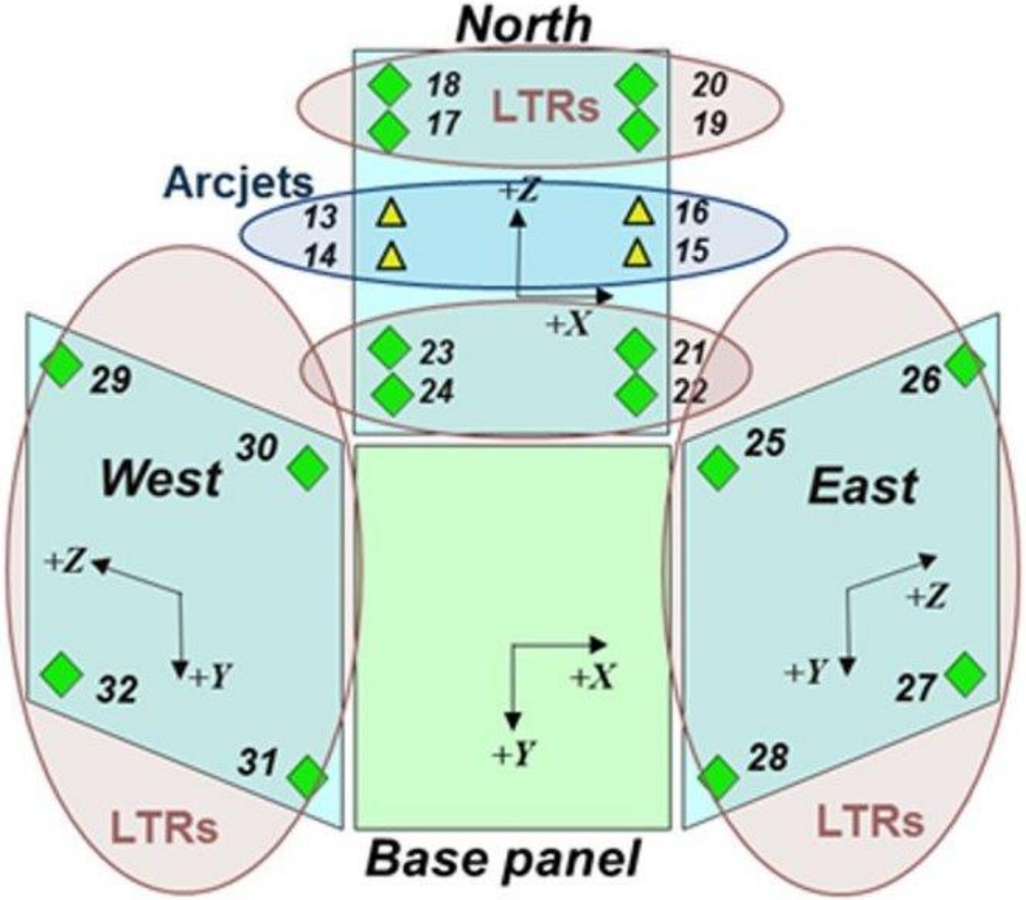
Thruster Issues

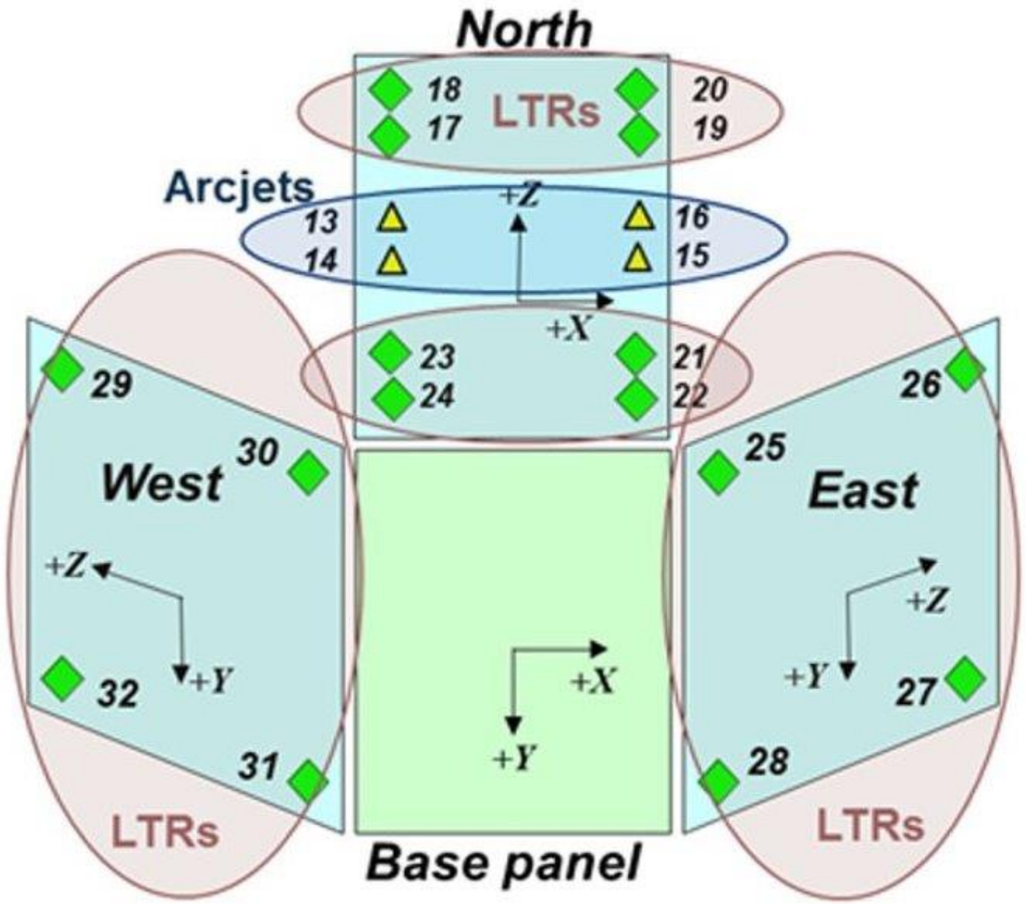
- AJT14 started acting strangely in 2020
  - Experiencing unexpected torques
  - Sending erratic voltage telemetry
- Various mitigations were tried:
  - Use the other AJT pair
  - Run in lower-power modes
  - Run in "unaugmented" mode
  - Use a different thruster type



Locations of AJT and LTR Thrusters for GOES-R Series Spacecraft.[1]

Fooling *FocusSuite*

- LTRs 18-22 could also be used for NSSKs
- However, *FocusSuite* restricts thruster selection when implementing NSSKs
- We developed a way to circumvent those checks



Locations of AJT and LTR Thrusters for GOES-R Series Spacecraft.[1]

Custom Maneuver Generation

- Heavily dependent on *FocusSuite*'s design
  - Make a standard impulsive NSSK
  - Edit maneuver file to convert to EWSK
  - Use *FocusSuite* to implement that EWSK
  - Convert back to NSSK
  - Compute momentum effects
  - Edit the maneuver file to include the new custom-made maneuver
- This creates the NSSK maneuver

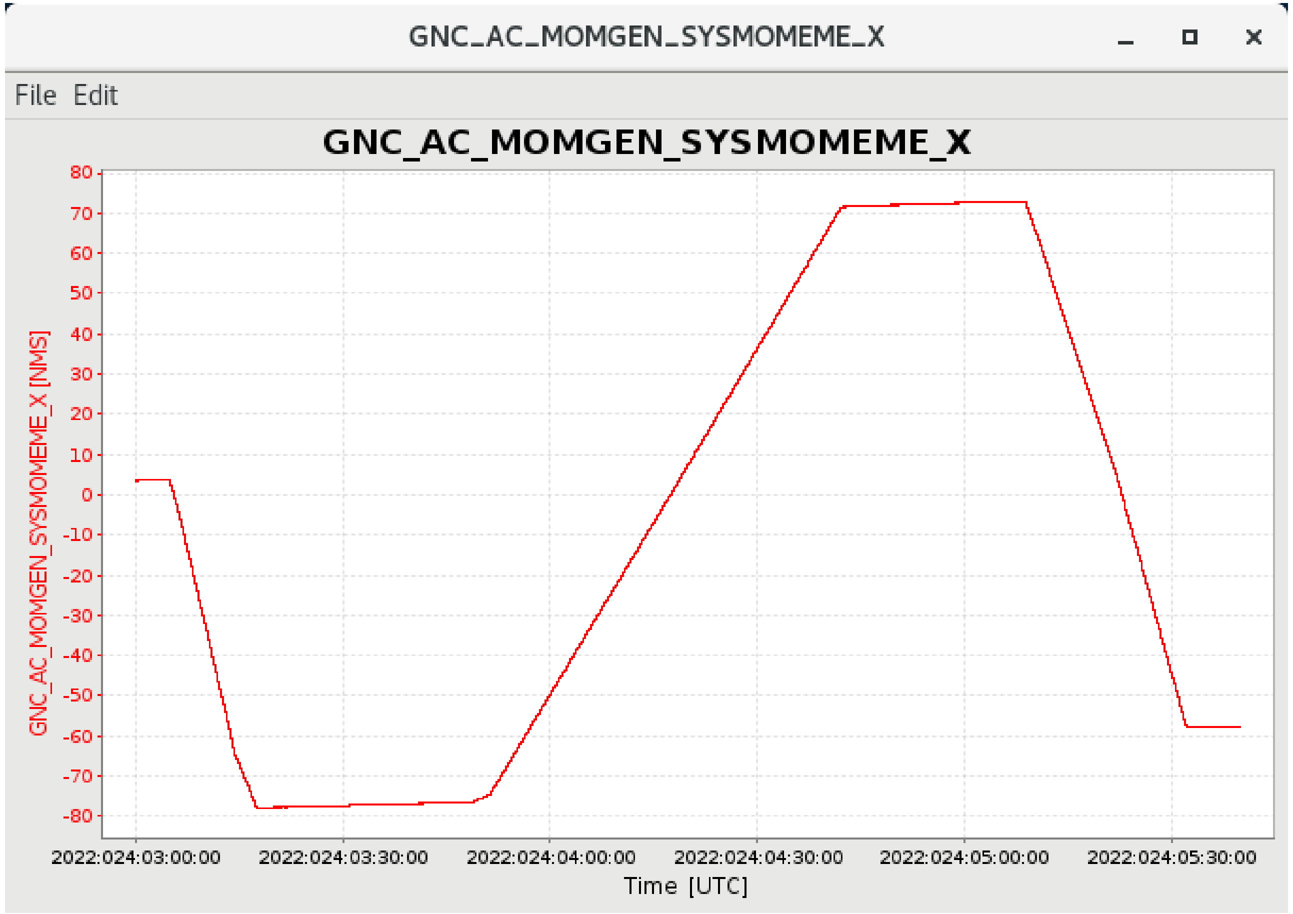
Anatomy of an NSSK

- NSSK maneuvers are usually long and impart a lot of momentum
- Reaction wheels have limits
- To stay within those limits, we use a "Pre-MA" to load momentum
  - We pass through zero momentum halfway through the NSSK burn

Maneuver Order During NSSKs.

Anatomy of an NSSK

- After the NSSK is over, we use a "Post-MA" to set a safe momentum state for the next day



Pre-MA and Post-MA Effects

- Pre-MA and Post-MA maneuvers are closed-loop
- Sometimes the spacecraft fires North-face LTRs
- This gives North/South ΔV
  - Sometimes >10% of the total from the entire NSSK
- Normally *FocusSuite* takes this into account, but can't with custom maneuvers

Solvers in *Autofocus*

- Finding the correct LTR NSSK ΔV is an iterative process
  - The Pre-MA, NSSK, and Post-MA North/South ΔV need to add up correctly
  - We use a proportional variable-gain numerical solver to do this
- There is a similar issue with the NSSK if it is too long
  - LTRs are lower-thrust than AJTs, so LTR NSSKs need to be much longer
  - We quickly start to run into momentum limit issues
  - If the LTR NSSK produces too much momentum, we know its duration needs to be capped
  - We use another proportional variable-gain numerical solver to target the momentum effect just below the limit

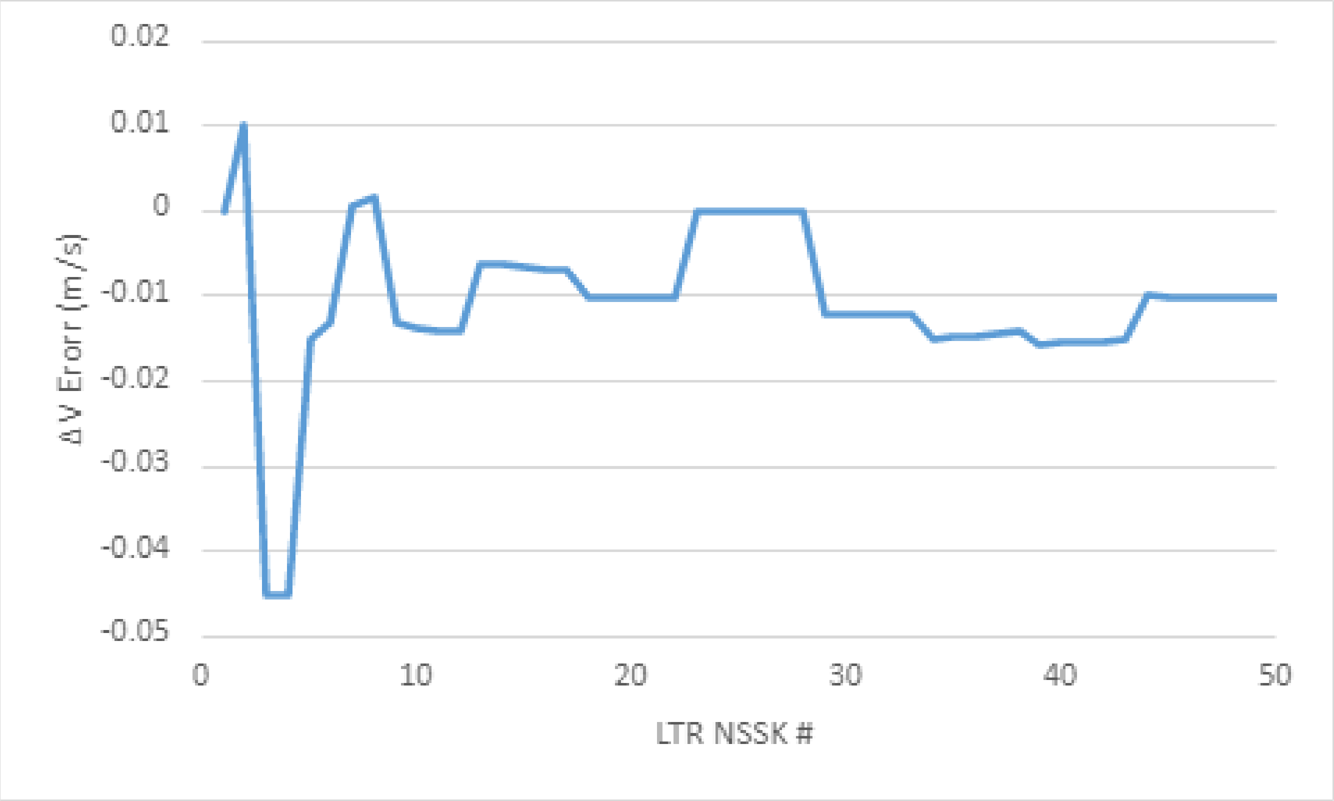
LTR NSSK Effects

- Lower LTR thrust means more NSSKs more often
  - Old maneuver cadence: NSSK, MA, EWSK, MA
  - New maneuver cadence: NSSK, NSSK, NSSK, NSSK, NSSK, EWSK, MA
- LTR NSSKs also take a long time to plan
  - Nominal planning takes about 90 minutes to plan 14 days' worth of maneuvers
  - Each individual LTR NSSK can take up to 40 minutes to plan

Results

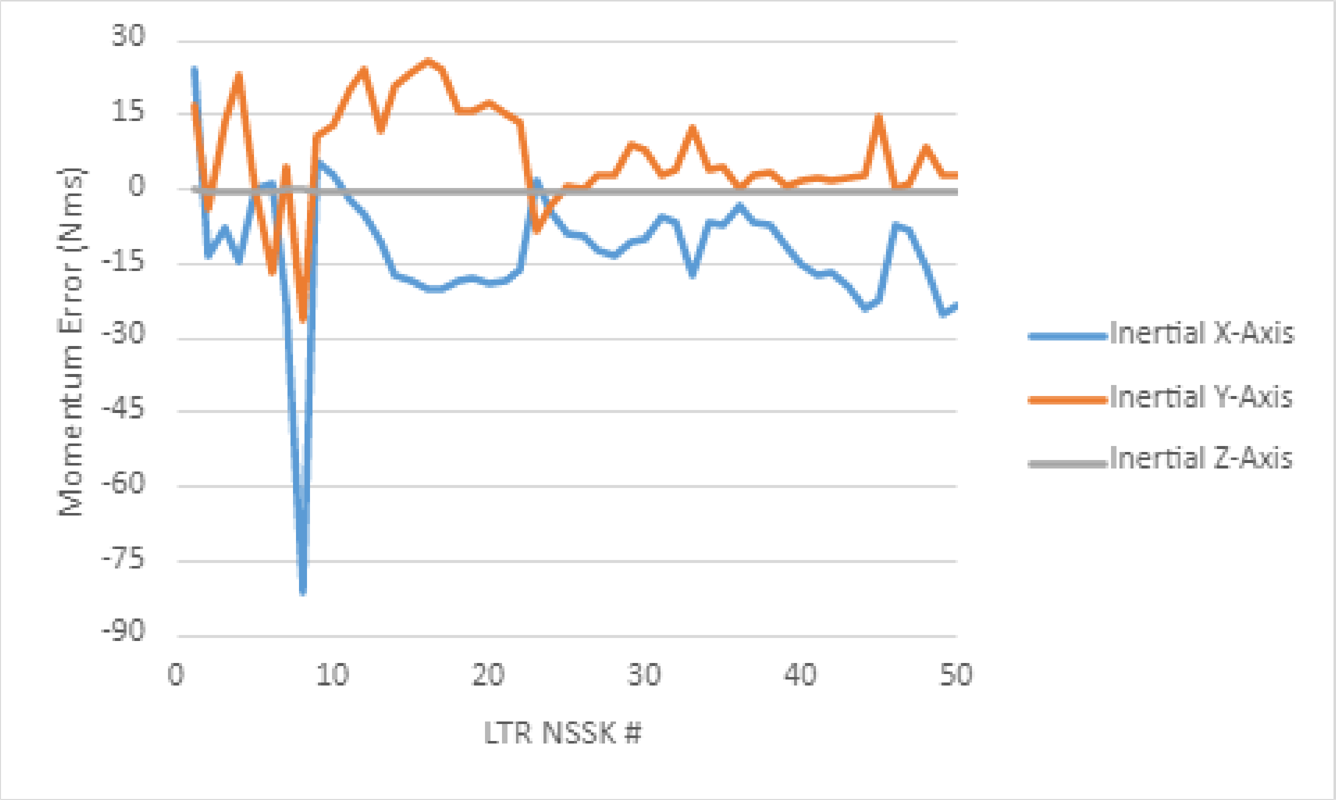
- GOES-16 has performed 52 LTR NSSKs so far
- There were some growing pains
- NOAA quickly switched to scaling past maneuvers
  - These can be generated in as little as two minutes
  - Predictions just as accurate as full LTR NSSKs

Prediction Accuracy



Difference Between *FocusSuite* ΔV Prediction and Observed Orbit Change for LTR NSSK Maneuvers.

Prediction Accuracy



Difference Between *FocusSuite* Momentum Predictions and Observed Momentum State Changes For LTR NSSK Maneuvers.

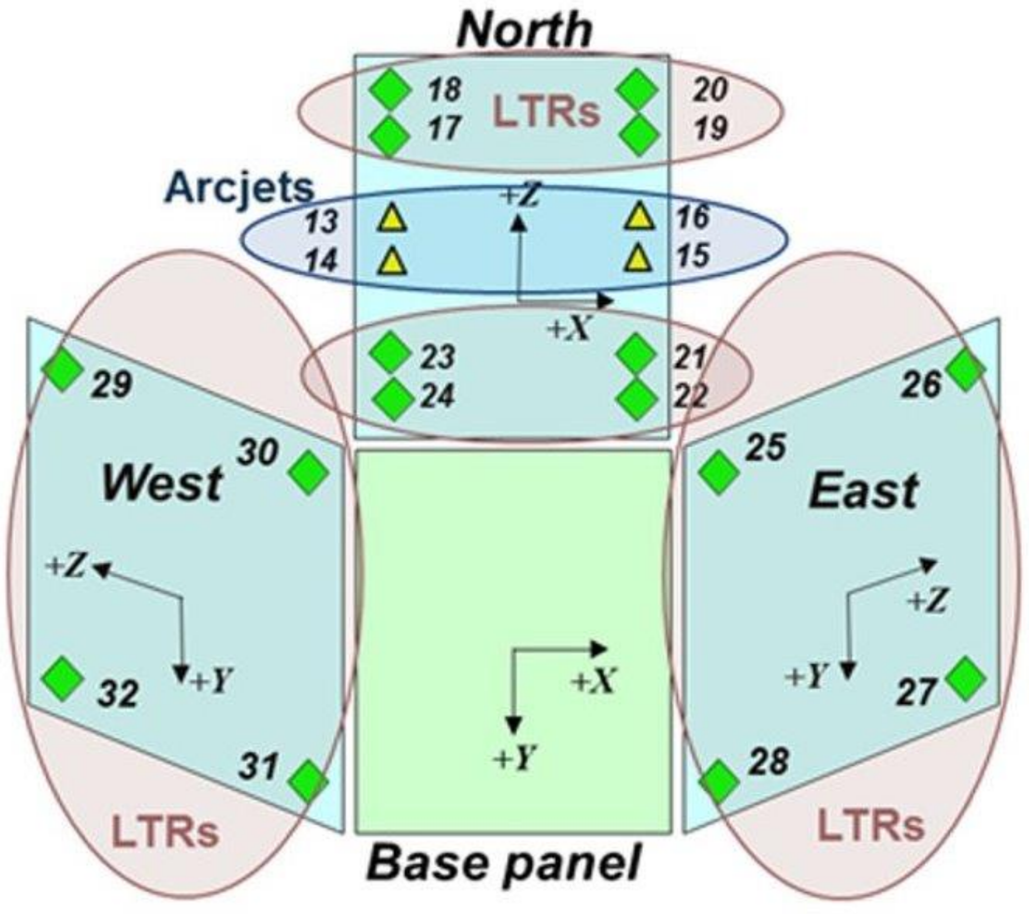
LTR NSSK Thruster Usage

Thruster Type	Total Duration (h)	Total ΔV (m/s)	Acceleration (m/s^2)	Total Fuel Usage	Fuel Efficiency (m/s/kg)
LTR	35.91	5.904	4.567×10^{-5}	12.95	0.4559
AJT	49.21	24.42	1.378×10^{-4}	15.51	1.574

Comparison of 50 LTR NSSK Maneuvers to 50 Nominal AJT NSSK Maneuvers.

Conclusion

- In October 2021, GOES-16 switched to imbalanced AJT NSSKs
  - These rely on the increased efficiency of AJTs to offset momentum imbalance
  - They use many programming tools developed for LTR NSSKs
- LTR NSSK maneuvers remain a contingency option



Locations of AJT and LTR Thrusters for GOES-R Series Spacecraft.[1]

Presentation References

[1] Chapel, J., Stancliffe, D., Bevacqua, T., Winkler, S., Clapp, B., Rood, T., Freesland, D., Reth, A., Early, D., Walsh, T., Krimchansky, A., “In-Flight Guidance, Navigation, and Control Performance Results for the GOES-16 Spacecraft”, *10th International ESA Conference on Guidance, Navigation & Control Systems*, Salzburg, Austria, 2017

[2] Gillette, J., Concha, M., "GPS Based Navigation Implementation for GOES-R", *39th Annual AAS Guidance and Control Conference*, paper 16-075, Breckenridge, CO, 2016

Questions?